SHUTTLE AVIONICS
DESIGN CONSTRAINTS & CONSIDERATIONS

A Guide Book

Based on KSC Engineering's Shuttle Turnaround Experience

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SHUTTLE AVIONICS TESTING CONSTRAINTS

- Objective - Consolidate within one report the operational Constraints and Considerations for launch site testing of the present Shuttle Avionics systems.

    - Constraint - Testing that requires special vehicle configurations and ground support equipment configurations.

    - Consideration - Testing configurations that have driven special infrastructure/ resource requirements, or have high failure rates.

- Purpose - To provide to the designers of future avionics systems the information required to possibly design out these concerns.

GENERAL 1.

INSTRUMENTATION COEFFICIENTS

Consideration

Due to performance requirements of various systems, sensor unique coefficient information is required.

Impact

- Special infrastructure required
- Investment required in configuration controlled databases at vendor, designer, and user
- Time and resources to operate software utilities to merge unique information onto software deliverables is required
- Procedures and utilities to update unique data at user site
- Can be a serial time constraint to testing if component is changed out

Design Objectives

- Provide systems with wider performance margins so nominal data can be used
- Develop more accurate and precise sensors where performance is critical
- Establish a flight test certification process that expands allowable margins for operational use, and thus expands the test requirements

GENERAL 2.

TELEMETRY DATA AVAILABILITY

Constraint

Multiple configurations of telemetry data stream constrains testing

Impact

Shuttle parallel testing is constrained in many circumstances by the need of a subsystem to be in a specific General Purpose Computer (GPC) memory configuration, GPC downlist format , or Pulse Code Modulation Master Unit (PCMMU) telemetry format load (TFL) to perform its subsystem flight checkout.

Design Objectives

- Create a telemetry system with sufficient bandwidth, and that will eliminate or, at least limit, the need for multiple telemetry formats (downlink and downlist).
- Limit the amount of telemetry to what is really required for operational health monitoring. Development flight instrumentation should be limited to prototype demonstrators for system certification only.

GENERAL 3.

AVIONICS COOLING

Constraint

Ground support for avionics LRU cooling required to operate avionics. In addition, avionics cooling requirements limit avionics activation and emergency power down responsiveness

Impact

- Coldplate cooled avionics boxes incur a large amount of operations overhead due to coldplate dings and GSE requirements for removal and replacement of these boxes.
- Loss of cooling requirements are very restrictive requiring vehicle power down if cooling loss is to exceed 5 minutes.
- SSME Controller requires special vehicle aft compartment air/GN2 purge
- Complexity of active fluid cooling loops constrains responsiveness and dependability of avionics operations

Design Objectives

- Develop passive cooling for avionics boxes to the maximum extent possible. If active cooling is required, air cooled avionics are preferred over pumped-fluid coldplate designs.
- If an active system is necessary, recognize the maintenance requirements and fully understand the requirements for cooling loss and minimize its impact to ground operations (e.g., the avionics devices should be tolerant to cooling loss for greater than the 15 minutes it takes to deactivate the vehicle.

GENERAL 4.

CONNECTOR RETEST

Constraint

Any connector demate requires continuity verification of every pin on that connector in order to certify functional integrity.

In some cases, the design precludes the use of functional retest to verify connector functions and required level of available redundancy. More exotic means must be used, such as Break-out-Box installation (an example is the Brake/Skid Control Box Fails that are OR'ed together at a Load Control Assembly, thus requiring intrusive means to determine particular Fail functionality or required level of available power redundancy.

Impact

- Innumerable unplanned functional retests required (even some planned demates that drive planned work)
- The GNC system (including its wiring, not just box connections) averages 659 connector pin invalidation's, on average, each processing flow
- Demates late in process flow invalidates previous certification for flight

Design Objectives

- Eliminate or minimize checkout requirements due to connector demates/remates
- Eliminate or minimize the need to demate flight connectors for checkout. For Troubleshooting, provide test points that also minimize the need for demate from flight certified configuration.
- Design avionics boxes with smart, low wire count communications methods. On Shuttle, an example of an intelligent, with low wire count connections is the Air Data Transducer Assembly (ADTA). Poor examples are the Aerosurface Amplifier (ASA) and Multiplexer/Demultiplexer (MDM).
- Ensure that all avionics functions requiring field certification are verifiable non-intrusively, that is, without the need of drag-on equipment.

GENERAL 5.

CONNECTOR MATED INDICATION

Consideration

Presently no way to automatically verify if all connectors are mated prior to testing.

Explanation: It is often required for hazardous or critical operations to know if a system's electrical configuration is operational. Example: an actuator must have at least one channel of control with hydraulic power applied. If no channels are connected, there is no control of the actuator. The rudder/speedbrake was once powered up hydraulically without knowledge that the command path connections were demated for troubleshooting not associated with actuator control itself. As a result, there was damage to the actuator. This could be economically disastrous if a gimballing engine moved in an uncontrolled manner into another engine (reference GNC 2. Engine Collision), or pose a safety hazard to personnel.

Impact

- Time and accounting infrastructure required to understand electrical configuration prior to power-on operations.
- Safety of personnel and flight hardware

Design Objectives

Out-of-configuration condition recognized (and preferably isolated) upon activation.

GENERAL 6.

PARALLEL SWITCH CONTROL

Consideration

Lack of parallel cockpit switch control from the ground on the Shuttle constrains automation

Impact

- Prevents automatic vehicle power up and power down
- Prevents automatic checkout of some component functions

Design Objectives

Provide parallel cockpit switch control from the ground for all power switches and many of the component functions to allow for checkout automation.

GENERAL 7.

MAN-IN-THE-LOOP

Constraint

Many Shuttle systems require Man-in-the Loop to perform system testing causing serial time impacts and variability of the servicing, maintenance and checkout processes

Impact

- Daily operations - Data Processing System (DPS), Environmental Control and Life Support Systems (ECLSS), Electrical Power & Distribution (EPD), and Instrumentation are all required to support all daily shuttle power-up operations. This results in a large level of support infrastructure (labor hours and equipment)

- Many manual switch actions are required to power-up, power-down and reconfigure these systems. The manual intervention occurs both in the vehicle, as well as at dedicated ground support equipment and facility locations to support daily servicing, maintenance, troubleshooting, and checkout. Prevents automation and takes time

- The manual actions in the vehicle are usually switch throws or gauge readings in the cockpit, but for fluid systems operation (such as hydraulics support for flight control activity) may involve hand valve operation, or operation of drag-on equipment such as aspirators, etc., all creating serial time delays, unnecessary activity in sensitive areas of the vehicle as well as a general heightened level of labor support and traffic.

Design Objectives

- For daily operations - allow ground command capability to power-up, power-down and reconfigure systems as required for turnaround.

- System checkout - when developing a new system, require the vehicle's avionics architecture to be flexible enough to be fully validated for turnaround. This should be accomplished by the vehicle autonomously from flight software application (preferably), or a ground automated sequence without manual intervention. in the vehicle or at remote sites (except for initiation).

GENERAL 8.

AVIONICS LRU ACCESS / MOUNTING

Constraint

Improve avionics line replaceable unit (LRU) access.

Impact

- Shuttle LRU access for troubleshooting and R&R in most cases is not user friendly. In the case of the OMS primary Controller, OMS Pod removal is required. As another example, the Accelerometer Assemblies require removal, replacement, and rectification of unrelated components which unnecessarily exposes sensitive and delicate coldplates. (Reference *GNC 12. Accelerometer Assemblies (AA's) Inaccessible*)

- Significant manpower needed to remove and replace components when mounting methods vary widely.

- Collateral damage often difficult to avoid. Example: A recent smoke detector removal and replacement damaged the Reaction Jet Driver - Forward (RJDF) # 2 causing extensive unplanned work.

- The wing body-mounted elevon actuators have no external panels for installation/removal access. Removal and replacement of these devices requires weeks of work perform and cannot even be performed at the pad in the vehicle-vertical position, which would result in a roll-back and destack.

Design Objectives

- Ergonomically designed access to LRU'S for troubleshooting and R&R purposes would greatly enhance ground operations.

- Consider military aircraft standardized black box mounting methods for rapid LRU changeout.

GENERAL 9.

AVIONICS LRU FASTENING DEVICES

Consideration

Fastening devices for installing avionics components should provide for trouble-free removal and installation and guaranteed for the lifetime of the vehicle (i.e., repetitive use).

> Explanation: Many of the fasteners used for Shuttle avionics components have been unreliable and costly to replace. The use of stainless steel inserts and stainless steel bolt and captive fasteners have led to galled threads, inability to install or remove, and uncertainty of flight certification torque values at the time of installation. Many fasteners require the measurement of running torque and final torque. In addition, the self-locking features of many of these fasteners are not satisfactory for repetitive installations. Costly component damage has resulted from these design deficiencies.

Impact

- Serial time delay to removal and replacement procedures.
- Damage to LRU and vehicle mounting areas.
- Unnecessary logistics burdens.
- Damage to sensitive coldplates, which are difficult to repair and replace.

Design Objectives

Design should provide for reliable installation and fastening devices. Need for simple, inexpensive, quick installation fastening devices without need for massive mounting system rework (including coldplates).

GENERAL 10.

AVIONICS LRU GROUND HANDLING EQUIPMENT

Constraint

The removal/reinstallation of many avionics components requires special ground support equipment (GSE).

Impact

- The installation and use of GSE for the removal and replacement of avionics components greatly increases the time required to accomplish this task.

- The cost of storing, maintaining and calibrating the equipment is onerous.

Design Objectives

Ergonomically designed access to flight components would enhance ground operations and eliminate the cost of designing, procuring and maintaining this GSE.

GENERAL 11.

AVIONICS BITE / TEST POINTS

Consideration

Lack of Built-In-Test-Equipment (BITE) and test monitoring points (available in the telemetry data stream) constrains the ability to know whether the required level of redundancy is available for commitment to flight (and retention of system certification from launch to launch). Also delays problem isolation.

Impact

- Numerous test monitoring points are required to isolate problems to the LRU level
- Avoid intrusive Break-out-Box connections and signal cross-strapping
- Reference also *General 4* and *General 5 (Connector mates/demates).*

Design Objectives

- Develop and demonstrate an avionics architecture for a reusable, orbital vehicle that has the capability of knowing whether its systems have retained their integrity (that is, have not lost functionality that forces loss of system certification) - automatically.
- Designing avionics with sophisticated BITE and numerous test monitoring points can greatly enhance ground operations capability to quickly isolate and replace problem LRU'S.
- Demonstrate that functional failures can be isolated without manual/intrusive troubleshooting tasks.
- Also reference design objectives in *General 4* and *General 5 (Connector mates/demates).*

GENERAL 12.

CRITICAL REDUNDANT POWER VERIFICATION

Consideration

Equipment's redundant power should be verified automatically upon power on.

Impact

- Manual/Serial redundant power verification tests using bus drop techniques, etc., are used to work around the constraint
    - V1161 - Non Hazardous Power Verifications
    - S0024 - Hazardous RCS Power Verifications
- Bus Drop techniques force cooling system reconfigurations (flight and ground) and man-in-the-loop

Design Objectives

- Automatic redundant power verification during vehicle power-up or system activation
- Continuos monitoring a goal
- Design out operating constraints to other systems or serial delays to the turnaround process
- Faults communicated and clearly isolated
- Reference also *General 3, Avionics Cooling* and *General 7, Man-in-the-loop.*

GENERAL 13.

SOFTWARE IN END-ITEM

Consideration

Software functions which are not embedded in the end item may result in added ground support personnel due to tendency to over-mange centralized software.

Impact

Change of actuator initialization (AI Mode) software, e.g. today requires elaborate Flight Software change process. Many actuator initialization functions should be embedded in the flight control system.

Design Objectives

Incorporate actuation functions, such as actuator initialization at the controller level, preferably by microcode so that software maintenance is contained and minimized and controlled by the end user.

GENERAL 14.

LOCAL OPF OPERATION

Consideration

Remote firing room control constrains OPF operations

Impact

Tremendous infrastructure and time involved to perform simple vehicle power-on tasks. Requires mobilization of and maintenance of large remote firing room facilities.

Design Objectives

- Move Orbiter ground checkout functions into or towards the vehicle to facilitate vehicle autonomy from GSE/monitoring, etc. If attempted, it must eliminate infrastructure costs and not simply add to infrastructure that already exists

- Maximize use of BITE (General 9) in the vehicle architecture

GENERAL 15.

UNPLANNED WORK

Constraint

Unplanned troubleshooting, repair and retest are way too high : approx. 50 %

Impact

Added work content, added time, task-to-task constraints, staff-hours, crew sizes, logistics support, etc.

Design Objectives

- Build and demonstrate dependability of systems/subsystems/components in all environments (flight/ground), such that the systems can be turned around repeatedly without unplanned maintenance actions

- Certify dependability of hardware through a rigorous flight test program and avoid putting immature hardware into an operational status (i.e., designs that perform well during flight, but then need a lot of maintenance every flight or two - a surprisingly large number of systems and technologies on the Shuttle fall into this category)
.
- Maximize mean time between failure (MTBF).

- Minimize intrusive work (i.e., inspections and routine turnaround tasks that require deconfiguring from flight certified condition)

GENERAL 16.

VENDOR DRAWINGS

Constraint

Lack of Vendor drawings, specifications constrains testing and troubleshooting

Impact

Unnecessary telecons/meetings with off-site personnel

Design Objectives

- Make all technical material available to launch site personnel
- Standardize documentation with regard to format and detail level.
- All technical material should be available on-line in standard formats. (Explore DOD CALS initiative, Boeing CATIA, etc.)
- Standardize all engineering documentation to open system COTS products

GENERAL 17.

HYDRAULICS

Constraint

Hydraulic systems cost enormous processing resources

Impact

- Large source of serial time impact waiting for hydraulics to come up
  - Observers required anytime hydraulics activated
  - Air content testing after any disconnect

- Present hydraulic actuation systems require extensive maintenance, ground pump units, etc.

- Present Flight hydraulic actuation systems require hazardous fuel systems

- Periodic desilting (hydraulic valve cycling) adds to processing burden

- Flight Hydraulics Fill and Bleed operations takes anywhere from 1 to 3 shifts

- Ground Support Equipment (GSE) power up and circulation required on a continual basis

- System design complicated by supporting thermal management systems:
  - Fluid line, tank and actuator heaters (and the fuel cell power necessary to operate them) - extensive thermostatic control and sensors required
  - On-board hydraulic fluid circulation systems, pumps, freon heat exchangers, etc. required for thermal conditioning on-orbit
  - Entry thermal management technology for hydraulics includes steam boilers (which also need heaters, etc. for on-orbit survival)

- Ground equipment, electrical continuity problems and ground services (such as samplings) required to support the above hydraulics thermal management systems.

Design Objectives

- Develop a maintenance-free flight control/landing-deceleration actuation system and demonstrate maintenance-free characteristics from launch to launch.

- Replace hydraulic actuation with electric actuation

- If hydraulics must be designed into the system, it must remain completely sealed to remain maintenance-free and component replacement-free (i.e., dependable) on turnaround

- Provide adequate instrumentation for troubleshooting leaks, valve and regulator anomalies, etc. (See attached horror story on troubleshooting a hydraulic regulator in the Shuttle landing gear circuit)

DPS 1.

MEMORY DUMP & COMPARE

Constraint

Shuttle memory "Dump and Compares" delay testing

Impact

- Time lost due to actual dump and compare operations
- Large infrastructure required to process tapes

Design Objectives

Design system capable of utilizing real-time hardware/software techniques to validate contents of memory, e.g. "checksums".

DPS 2.

MASS STORAGE DEVICE CAPABILITY

Constraint

A faster method of loading the Mass Storage device is needed

Impact

The Shuttle's Mass Memory units are magnetic tape storage devices that require loading from the LPS system , up the LDB, to the on-board computer which is in a special memory configuration, then to the mass memory unit . Loading a MMU takes 1hr 40mins, dump and compare a MMU takes 1hr 10mins , and many off line hours are worked processing memory tape products.

Design Objectives

- Develop a "hard drive"' system that can be loaded from a disk drive. Loading from a disk, and dumping to a disk could greatly simplify load, dump and compare operations (assuming dump and compares are required).
- Explore megneto-optical drives where cartridge could be loaded on the ground and “popped” in to flight drive.

DPS 3.

GPC MULTIPLE MEMORY CONFIGURATIONS

Constraint

Each Shuttle on-board computer operation requires being in a unique memory overlay configuration.

Impact

- Some ground operations require the on-board system being in a "flight OPS" which have operational and safety considerations.
- Special GPC memory configurations for RMS, cargo, KU communication and MMU testing constrains scheduling flexibility.
- Operations which require differing LDB configurations must wait upon one another. For example, some hazardous activities require redundant launch data busses (LDB's), such as many hydraulic activities and hypergolic servicing. A single LDB configurations examples are one LDB connected to a G9 machine and the other LDB connected to a P9 machine. Therefore, operations requiring redundant LDB configurations must run serial to those operations requiring the single LDB/multiple memory configurations.

Design Objectives

- Perform all operations in a single memory configuration.
- Provide data bus connectivity to on-board systems from the ground to provide independent control.

DPS 4.

LAUNCH BUS SPEEDUP

Consideration

Shuttle Launch Data Bus (LDB) is too slow

Impact

- Slow speed limits time between commands going up the bus
- Slow speed limits quickest time critical SAFING command can get out

Design Objectives

Increase speed of Launch Data Bus

DPS 5.

MDM RETEST

Consideration

Single failure in an MDM requires massive retest of unrelated systems

Impact

Activation of end item systems (mobilizing a level of ground support above and beyond that needed for DPS checkout) takes time and adds work content

Design Objectives

Insure that DPS components can be recertified for flight readiness without activating end item functions (RJD trickle current verification is an innovative example of how to do this)

DPS 6.

CRT VIDEO OUTPUT

Consideration

Provide the ground visibility of the on-board CRT's.

Impact

- Since the ground cant see the on-board CRT's, any problems requiring CRT output knowledge introduces guesswork and uncertainty.

Design Objectives

Provide CRT video output for ground display capability.

GNC 1.

INDEPENDENT CONTROL OF ACTUATOR POWER

Constraint

When operational requirements call for simple, single surface movement, a lack of independent control of actuator power results in the mobilization of large, time consuming ground support (hydraulics, and other local & remote support) for control and monitor of *all* surfaces.

Impact

Mobilization of large ground infrastructure (including large number of observers) for simple mechanical tasks

Design Objectives

Default actuator power to a disabled state during ground operations. Allow power to be enabled to actuators independently.

GNC 2.

ENGINE COLLISION

Constraint

Engine collision should be mechanically impossible

Impact

- A great deal of software and procedures must be developed and maintained to prevent collision between engines
- Adds task-to-task constraints
- Adds time at console operator station to manage a safety issue that could be avoided during the design process
- Engine "Toe-in" clearance test requirement

Design Objectives

Engine collision should be mechanically impossible in the propulsion system layout

GNC 3.

SSME HYDRAULIC CIRCUITS ISOLATION

Constraint

TVC hydraulics cannot be isolated from SSME cryogenic valve hydraulic circuits .

Impact

When TVC engine positioning is required, opening the MPS TVC Hydraulics isolation valve applies hydraulics to both the TVC and the SSME cryogenic valve circuits. To hold the SSME cryogenic valves in their safely closed position, one of two conditions must be met :

- SSME Controller power must be applied
- MPS pneumatics must be applied to the SSME

Thus the SSME system configuration is a constraint to the TVC engine positioning.

Design Objectives

Provide isolated supplies to each subsystem.

GNC 4.

ENGINE MAINTENANCE DRIVES COMPLEX & LENGTHY MECHANICAL OPERATIONS

Constraint

Undependable engines for turnaround that require either intrusive, in-place maintenance or outright removal, drive a requirement for thrust vectored flight control systems to validate adequate clearance for gimballing. This is required to assure that newly reconfigured/rerouted/reconnected fluid and electrical lines do not exhibit cable stretch, interference, etc. In addition, complex heat shield mechanisms are required to be checked for binding, proper hot-gas sealing, etc. Our experience is that the propulsion system technicians do uncover anomalies after having restored the engine/propulsion system to its flight certified configuration.

Impact

- Requires extra thrust vector control (TVC) clearance tests (hours)
- Requires extra movement of nozzle for installation.
- Tremendous serial time delay associated with engine heatshield removal and re-installation (days and weeks).
- Large potential for flight hardware damage and personnel injury. Large amount of time and resources spent overcoming these hazards.

Design Objectives

- Design a propulsion system that leaves engine/flight control interface intact, i.e., flight certified configuration. (No de-pinning of engine thrust vector control actuators from engines, disconnection of engine to vehicle electrical cables, fluid lines, etc., as well as no removal of engine heat shields required for turnaround maintenance, servicing)
- Simpler engine heat shield design or open engine compartment with no need for complex heat shield mechanisms.

GNC 5.

SRB TVC FLEX BEARING RESTRICTION

Constraint

SRB TVC Flex bearing limit of 3 degrees requires control by procedure/software

Impact

Added software/procedural management and overhead

Design Objectives

Keep flight/ground operating limits common and design out special configurations in special conditions

GNC 6.

SRB NOZZLE FLEX BEARING TEMPERATURE

Constraint

Prior to vectoring the SRB nozzle, the average flex bearing temperature over the past 24 hours must be 50 ° F or greater. The average temperature is calculated using a sample every 3 hours for the 24 hours preceding nozzle vectoring

Impact

- The SRB must be powered up for at least 24 hours before nozzle vectoring
- Time and manpower is consumed performing the necessary data retrievals and calculating the averages.

Design Objectives

Design a vectored nozzle with a flexible bearing that is less sensitive to temperatures above freezing.

GNC 7.

EXCESSIVE AEROSURFACE POSITIONING REQUIREMENTS

Constraint

Due to high maintenance activity on aerosurface structures, thermal protection and hinge-line thermal seal mechanisms, an excessive amount of support is required of the flight controls and hydraulics subsystems to reposition or stroke the surfaces.

> Explanation: A large amount of maintenance activity (weeks) has been experienced on elevon and body flap hinge line areas. The maintenance has been due to thermal stress, erosion and general wear and tear on hinge line seals and mechanisms required to prevent hot plasma causing damage during entry flight between the upper and lower surfaces at the hinge line. Panel warp, slumping of thermal protection items and time spent re-aligning and re-rigging have been experienced.
>
> In addition, low tolerance margins for corrosion due to low skin thickness design, atomic oxygen in the on-orbit environment and normal ambient humidity have been stated as contributing factors. This has been a problem most prevalent in the rudder/speedbrake area.

Impact

Unnecessary mobilization of ground equipment and labor to reposition aerosurfaces for aerosurface wear and tear corrective action.

Design Objectives

Design and demonstrate maintenance-free aerosurfaces including structural thermal protection as well as aerosurface hinge line thermal protection.

GNC 8.

NOSEWHEEL STEERING (NWS) TESTING

Constraint

Nosewheel steering (NWS) testing requires complex time consuming gear configurations and Ground Support Equipment.

Impact

- De-pinning torque arm
- Rate of caster ground support equipment (GSE) required
- Requires mobilization of ground hydraulic equipment and activation of flight hydraulic system
- Specific gear configuration required (gear extended). Control box access requires gear down (inaccessible in launch configuration)
- Steering Position Amplifier/Transducer (SPA/SPT) connectors are demated every flow due to landing gear pyro removal
- Requires pyro connector demates or interrupt boxes installed for testing some signals routed through Forward Reaction Control System pod
- Dedicated Display Unit power required for position transducer and amplifier (should be powered by control box to avoid inter-system task to task constraints)

Design Objectives

- Design, build and demonstrate NWS system that requires no special GSE for checkout, nor requires any de-configuration of vehicle
- Consider electromechanical actuation

GNC 9.

BRAKES/ANTI-SKID MAINTAINABILITY

Constraint

- Testing requires wheels and tires installed, ground support equipment which adds set-up time and serial delay and logistics support for the GSE
- Tires are replaced every flow. If flight tires not available for brake testing, roll-arounds must be used (another instance where the vehicle is required by design to be taken out of flight certified configuration)
- Brake balancing is not self-adjusting (requires manual setting of potentiometers by technician for proper puck/servo balancing)
- Brake stacks are designed to be removed every five flights unless damage found. Experience is that, even after the carbon brake and parachute modifications, we are still having to remove every two or three flights. This is an improvement over the old beryllium brakes and no parachutes, but wide of the mark of a dependable, maintenance-free landing gear/brake system.

Impacts

- Requires ground hydraulics systems mobilization/flight systems activation
- Requires landing gear extension for brake control and anti-skid system validation
- Weight-on-wheels (also known as “squat switches”) and weight-on-nosewheel paddles requires man-in-the-loop for landing gear checkout
- Rudder/brake pedal ground support equipment required for brake balancing
- Special shop aid required to test new stacks
- Wheel speed sensor have been damaged during brake stack removals and replacements.

Design Objectives

- Need dependable, standalone, self-checking, self -balancing, autonomous brake/anti-skid test & checkout
- Self-adjusting (tuning) control box
- Drag chutes have alleviated brake problem somewhat, but still a high maintenance area. Heavy maintenance requirement on the current chute deploy scheme.

Note: Need for thoroughly understanding vehicle braking margins up-front. Don’t under-design the landing gear system. Do bring in control system design experts up-front for brake/anti-skid control box and actuation design.

GNC 10.

REACTION CONTROL SYSTEM (RCS) VERNIER DRIVERS

Constraint

RCS Vernier Jet driver circuit checkout requires area clears for personnel safety.

Explanation: A trickle current method of verifying driver circuit integrity is used for Built-in test. While this method has proven very successful and responsive for the larger Normal jets, the circuitry has a design flaw that allows the possibility of releasing hypergolic fuel for the smaller vernier jet trickle current testing. This constrains personnel from working near areas where there are vernier jets. This in turn causes a serial delay while waiting for areas to be cleared of personnel and equipment sensitive to hypergolics and prevents other testing a parallel maintenance work from continuing.

Impact

- Serial delay to test activities while areas are cleared of personnel and equipment sensitive to hypergolic fluids.
- Unable to perform parallel work activities not related to RCS testing because of area clears.

Design Objectives

This operational constraint is due to a known design deficiency for which a simple known design fix has existed for many years. Due to up-front cost considerations for fixing the design, the fix has never been implemented.

Future vehicle designs should provide ability to checkout these thrusters electrically without requiring any area clears.

GNC 11.

RCS DRIVERS - DRIVER POWER ACTIVATION

<u>Constraint</u>

Reaction Control System (RCS) driver power testing requires a complete pad surface clear or an OPF bay clear. This is due to the design of the driver circuitry

Explanation: The driver circuitry is very simple, consisting of a Darlington pair transistor module mounted on a heatsink. The driver circuit is controlled by much more complicated logic circuitry which requires two separate commands to activate the driver circuitry. Power for the logic circuitry and driver circuit is separate (i.e., logic power and driver power). With driver power activated, the driver circuitry is a single point failure that could lead to the firing of an RCS thruster without either command being on. Therefore, anytime the driver transistors are supplied with 28Vdc driver power, a single hardware failure would lead to a thruster firing.

<u>Impact</u>

- stops all other work
- personnel safety issues
- single point failure with serious flight/mission concerns

<u>Design Objectives</u>

- Eliminate single point failures from reaction control system driver electronics which would cause an uncommanded thruster firing.
- This operational constraint is due to a known design deficiency for which a simple known design fix has existed for many years. Due to up-front cost considerations for fixing the design, the fix has never been implemented.
- Future vehicle designs should provide ability to checkout these thrusters electrically without requiring any area clears.

GNC 12.

ACCELEROMETER ASSEMBLIES (AA) INACCESSIBLE

Constraint

Accelerometer Assemblies located behind Avionics Bay

Impact

- Troubleshooting/repair/checkout requires removal of other components
- Possibility of collateral damage to other avionics/structures/active thermal systems during turnaround while accessing AA hardware

Design Objectives & Considerations

- Make all avionics components accessible such that no other functions are disturbed or taken “out-of-print” (reference *General 8. Avionics LRU Access / Mounting*)
- While mounting the box on a heatsink was good (prevented cold-plate mounting), accessibility was sacrificed.
- Reference *General 8, Avionics LRU Access.*
- Current test & checkout scheme is responsive (minutes) with little or no warm-up.

GNC 13.

INERTIAL MEASUREMENT UNIT (IMU) HEALTH ASSESSMENT

Consideration

IMU health determination more of an "art" than science

Impact

- Inordinate amount of time spent and a dedicated Inertial Systems Lab (ISL) support infrastructure required for tracking, calibrating and managing mechanical errors for turnaround
- Periodic calibration of spare units requires permanent design center lab support (ISL)
- Great deal of experience required to even speak the language
- Shuttle IMU's require significant care with regard to warm-up time and time and cycle maintenance requirements

Design Objectives

- Need rapid, autonomous navigation system health determination
- Fully understand test margins required to "align and fly" the vehicle, and not just characterize hardware for maximum performance out of the device.
- Demonstrate self calibration and no need for on-line lab support nor software tailoring by LRU
- Investigate use of strap-down inertial systems using high accuracy Ring Laser Gyros and accelerometers, coupled with Global Positioning System (GPS).
- Incorporate new technology inertial sensors (solid state sensors, RLG, etc.) such that accuracy of system eliminates need for expert support
- Design navigation system such that IMU data can be supplemented by another navigation system such that IMU performance can have less strict tolerances

GNC 14.

STAR TRACKER LENS & LIGHT SHADE INSPECTION

Constraint

Star Tracker lens and light shade inspection requires clean room environment

Impact

- Clean room setup and access
- Cleaning
- Cover install and remove
- Light Shade sensitive to operational damage, causing unplanned work
- Thermal system damage due to door operation

Design Objectives

- Design out optical star tracker systems if simpler approaches are available
- If star trackers must be used, do not design-in dedicated mold-line penetrations (doors) and active doors mechanisms.
- There should be no special cleaning/access requirements
- Design robust hardware that is more immune to physical damage
- Νοτε: Electronics dependability of the Star Tracker avionics has been good overall (although, some false annunciation’s during self-test have been noted)

GNC 15.

STAR TRACKER CONTAMINATION

Constraint

Star Tracker optics is susceptible to contamination and damage caused by handling, outgassing, humidity, and tile debris.

Impact

- Requires periodic removal for cleaning and refurbishment of light shades and protective window assemblies
- Requires inspection to verify flight worthiness
- Storage of light shade not easily accommodated at KSC because of high humidity

Design Objectives

- Design out optics if simpler approaches are available
- Design robust hardware that is more immune to contamination and physical damage
- Design in ability to maintain hardware in place
- Eliminate or reduce the use of materials that outgas

GNC 16.

ENTRY AIR DATA SENSORS UNDEPENDABLE

Consideration

Current Air Data Transducer Assemblies (ADTA) pressure sensors are undependable due to transducer drift

Impact

- Requires complex ground support equipment (GSE) for calibration every turnaround
- Many recycles to vendor for sensor rework adds to spares level burden and overall logistics repair burden
- Air Data Test Set hook-ups and operation required every flight. Adds set-up time, more equipment that needs to be depended upon for a “green light GO” from the system and GSE maintenance and vendor support costs.

Design Objectives

- Provide pressure sensors with no drift characteristics allowing simple self test without pneumatic ground hookups during ground turnaround (only for depot level maintenance)
- Mean Time Between Maintenance (MTBM) of space flight air data technology must be improved by orders of magnitude and flight and ground operations certified.
- Build flight control system that computes air data parameters from navigation equipment, rather than utilizing traditional direct air-stream sensing.

GNC 17.

DEPLOYABLE ENTRY AIR DATA PROBE MAINTENANCE

Constraint

Deployable Air Data probes result in extra work

Impact

- Tile maintenance
- Tile repair
- Checkout, repair and alignment of deployment mechanisms
- Current technology makes contamination of ports critical

Design Objectives

- Design-out complex deployment mechanisms and mold-line penetrations.
- Demonstrate passive, simple, low maintenance air data collection system integrated with GNC functions. Re-explore flush-mounted air data sensors such as Langley’s OV-102 Shuttle Entry Air Data System (SEADS) for improved operations, maintenance and redundancy (not for improved performance).

TELECOMM 1.

HOLLOW RF WAVEGUIDES THAT PENETRATE PRESSURIZED STRUCTURE

Constraints/Considerations:

A Ku-Band RF system uses hollow waveguides that penetrate the pressure hull.

Impact:

The waveguide require purge air and desiccants to prevent condensation and corrosion. They also require cabin air pressure to prevent corona, and must be leak checked. These are labor intensive efforts.

Design Objectives:

Use only coax cables or waveguide filled with solid dielectric. No hollow transmission line aperatures (such as waveguides) should penetrate the walls of the pressure vessel. This will reduce critical failure modes and the need for leak tests.

Contact: Phil Metzger, NASA KSC TV-ETD-3, 407-861-3740

TELECOMM 2.

HAZARDOUS RF SYSTEMS & GROUND ANTENNA COUPLER REQUIREMENTS

Constraints/ Considerations:

RF Systems frequently require extensive GSE Antenna Coupler setups and Radiation hazards impede processing.

Impact:

Potential radiation hazards from high power RF systems require clear that inhibit vehicle processing in the immediate area. Additionally, antenna coupler setups require precise positioning to ensure repeatable transmission losses needed for testing and troubleshooting.

Design Objectives:

1. For hazardous RF systems provide an onboard test load and GSE port to hook up an RF hardline. This will eliminate radiation hazard clears and enable better testing and troubleshooting.

2. Implement program policy to direct Radiation Protection Officers and Safety offices to abide by ANSI standards regarding hazardous non-ionizing radiation controls. ALARA (As Low As Reasonably Achievable) principles should not apply to operational non-ionizing radiation programs.

Contact: J.D. Collner, NASA KSC TV-ETD-3, 407-861-3745

RMS 1.

AUDIBLE TESTING

Constraint

Some RMS testing requires "listening" for sounds of motor operation to test equipment

Impact

- Time consuming, accessibility issues
- Subjective test criteria (difficult to calibrate and standardize ear/brain systems)

Design Objectives

All checkout functions for motorized systems should be automatic using objective criteria

SSME 1.

SSME INSTRUMENTATION CALIBRATION COEFFICIENTS

Consideration

During the processing flow and prelaunch it is required to perform an automated checkout and calibration of the SSME pressure sensors. To accomplish this, all helium must be vented off the SSME to perform an accurate calibration.

Impact

- Serial time to vent and reapply helium
- Causes unreliable readings of mass spectrometer due to background He in the OPF
- Venting is noisy
- Waste of helium

Design Objectives

- Allow a calibration to take place with helium applied
- Eliminate the need for a calibration by providing nominal coefficients

GLOSSARY / ACRONYMS

AA - Accelerometer Assembly

DPS - Data Processing System

ECL - Environmental cooling loops

EPD - Electrical power distribution

GPC - General purpose computer

GSE - Ground support equipment

IMU - Inertial measuring unit

INS - Instrumentation systems

LDB - Launch data bus

LPS - Launch processing system

LRU - Line replaceable unit

MDM - Multiplexer Demultiplexer

MPS - Main propulsion system

NWS - Nosewheel steering system

OPF - Orbiter processing facility

PCMMU - Pulse coded modulation master unit

R&R - Remove and replace

RCS - Reaction control system

RMS - Remote manipulator system

SSME - Space shuttle main engine

TFL - Telemetry format load

TVC - Thrust vector control